

ARMY RESEARCH LABORATORY



Artillery Delivery of LWIM Systems

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Abstract

The Defense Advanced Research Projects Agency (DARPA)-funded Low-Power Wireless Integrated Microsensors (LWIM) program is a partnership between the UCLA Department of Electrical Engineering and the Rockwell Science Center directed to the co-development and commercialization of LWIM for military applications. LWIM will provide a network of distributed, autonomous, low-power microelectromechanical systems (MEMS) sensors and actuators coupled with a wireless network. This report discusses issues associated with artillery deployment of the system and proposes a round to accomplish this task.

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1. Introduction

The Defense Advanced Research Projects Agency (DARPA)-funded Low-Power Wireless Integrated Microsensor (LWIM) program is a partnership between the UCLA Department of Electrical Engineering and the Rockwell Science Center directed to the co-development and commercialization of LWIMs for military applications. LWIMs will provide a network of distributed, autonomous, low-power microelectromechanical systems (MEMS) sensors and actuators coupled with a wireless network. This report discusses issues associated with artillery deployment of the system and proposes a round to accomplish this task.

The LWIM system (LWIMS) is composed of several different types of sensors, each type with a different field of view (FOV). Each sensor relays its information back to a long-range radio. This transmitter then resends information back to an information-processing center. The pattern of ground coverage and ability of a sensor information to reach the long-range radio define the overall system performance.

Problems associated with packaging, launch, and final dispersion are discussed. The packaging of a round defines how the subsystems and components are specified, arranged, and assembled within a round, and how they are ejected. Launch issues center on the mechanical stress caused by the forces during the launch of the projectile and how different packaging schemes are employed to mitigate these stresses. Dispersion refers to pattern and orientation of the components on the ground. The Advanced Munitions Concept Branch, U.S. Army Research Laboratory (ARL), has the experience and design tools available to resolve these problems and the resources to provide proof-of-concept fabrication and testing for the artillery-deployed LWIMS.

2. Background

Many interrelated issues must be addressed when developing a new weapon system. Several iterations are required before a design is finalized. These issues include the system's purpose, characteristics, and properties of the system components, and the method of delivering the system to the battlefield. In this case, the delivery of a battlefield surveillance system by artillery is considered, focusing on conceptual proposals for packaging and dispensing the system components. The current and projected status of LWIM components, together with experience gained from other systems delivered by artillery, has led to the design iterations described in this report.

LWIM technology has progressed rapidly in the last several years. A report by Asada et al. (1998) summarizes the status of the design and fabrication of the individual modules, or components, which make up a node in a self-organizing network of sensors. The combination of sensors, processors, and low-power radio transceivers, together with the proposed network architecture, keeps power requirements to a minimum. A combination of sensors, signal processing, and a low-power transceiver make a node. A single long-range high-power radio (i.e., communication submunition) can provide communication to an operations center. The military has a message format system, so the LWIM message protocol will eventually need to follow this protocol. Earlier reports provide more detailed information on the development of individual modules and the network architecture. The Rockwell Science Center has developed a prototype sensor node and is working on reducing the size of the node to the dimensions assumed in this report. A picture of the proposed LWIM sensor is shown in the upper left section of Figure 1. This sensor is 1.150 in in diameter and 0.720 in thick, and the developers have stated that this is the size toward which they are working.

There are several methods of delivering a surveillance system to the battlefield. For some combinations of sensors and applications, hand emplacement might prove the only way to ensure precise sensor coverage at the desired location. An unmanned aerial vehicle (UAV) could provide another method of delivering a system. This method would minimize the risk to

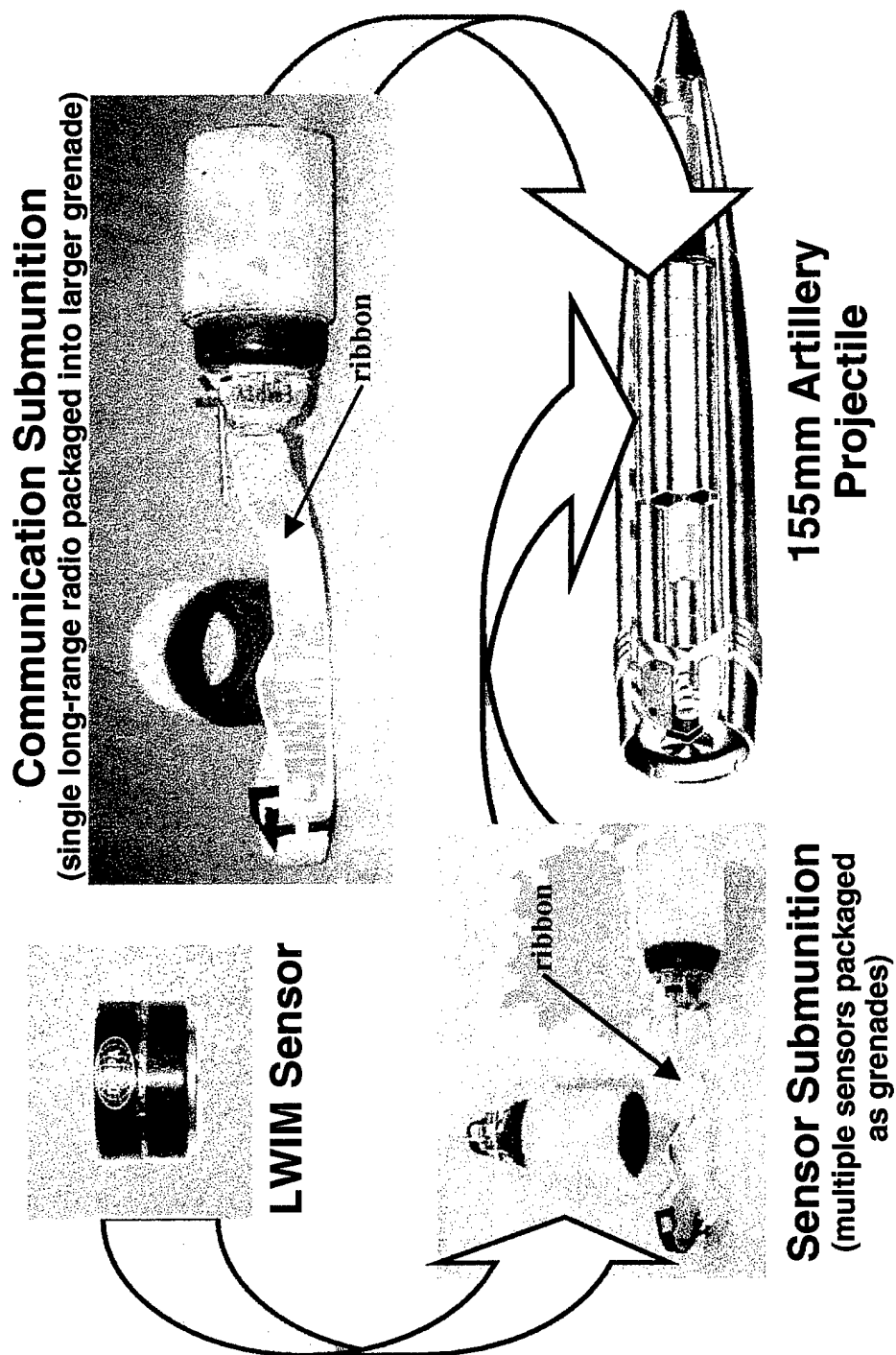


Figure 1. Artillery-Delivered LWIM "Cargo" Munition Concept.

personnel while still providing potentially excellent accuracy in emplacement. However, when speed of deployment is an issue, UAVs might not be appropriate. For fast deployment, delivery by artillery seems most appropriate. The overall LWIM concept of a network of many small and low-cost sensors distributed over a large area fits well with an artillery-delivered system.

Artillery delivery requires that the individual components be shock-hardened to withstand a force of up to 15,000 g.

Delivery system accuracy and precision must be considered in any analysis of a complete LWIMS. Thompson (1990) has analyzed some theoretical issues associated with optimizing aimpoints given certain types of errors. Target location error (TLE) is typically one of the driving factors in artillery system performance. Presumably, an artillery-delivered LWIMS would be aimed at known map coordinates, thus reducing the TLE to zero. Leitzke and McGee (1997) have studied the effect of reducing the TLE on the overall system effectiveness of a sense and destroy armor missile (SADARM)-like round with a sensor footprint of about the same magnitude as a network of LWIM nodes. There are large amounts of data available on total artillery system errors, and detailed error budget analyses have been performed as a step toward increasing total system accuracy and precision.

The XM982 round promises greatly increased accuracy and precision together with extended range capability. Fins help to provide a stable platform for GPS and inertial navigation units and also provide lift for glide and guidance phases of the trajectory. Since the XM982 is designed to accommodate a variety of payloads, the projected capabilities of this round make it an ideal LWIMS deployment system.

Several 155-mm artillery-delivered munitions have components and system characteristics that make them especially relevant to an artillery-delivered LWIMS. One such munition, the M864 round, dispenses 72 M42 grenades directly from the projectile by pushing them out the back with a secondary expelling charge (see Figure 1). Test results show that the grenades typically are roughly uniformly distributed in a circular pattern with a radius of between 50 and

75 m. The radius varies somewhat as a function of range (which, in turn, depends on muzzle velocity and elevation angle) and the altitude at which the grenades are dispensed. Sedney (1978) suggests that the lightweight LWIM sensors might not disperse as readily as the relatively heavy grenades, if they were to be dispensed using the same method under similar conditions. Changing the ballistic coefficient of the sensors by modifying their shape and weight or attaching ribbons to them would involve tradeoffs that would have to be analyzed to determine optimal design.

A modified version of the SADARM M898 munition may be a more attractive for the LWIMS. Two SADARM submunitions are dispensed from the M898 round (see Figures 2-4). Figures 2 and 3 are cutaway views of these munitions. Figure 4 depicts the SADARM submunition canister with its parachute deployed. Figure 5 depicts a typical deployment scenario of the SADARM system. The submunitions are composed of two canisters, which are deployed from the projectile at an altitude of approximately 1,000 m. The method of deployment, together with the dimensions and weight of the canisters, gives them a separation of about 100 m. The canisters are suspended from parachutes that are designed to achieve a particular sensor footprint. SADARM rounds are expensive; however, most of the expense is due to the onboard sensors, processors, and warheads, and not due to the canisters and parachutes. Presumably, if LWIMS components, to include a long-range radio, can be miniaturized to fit into the SADARM-sized canisters, the canister deployment mechanism and the parachutes can be designed to achieve flight patterns more appropriate for optimal delivery of the LWIMS.

Given some characteristics and properties of proposed LWIMS components, together with a preference for artillery delivery, this report documents an initial effort to design and package the LWIMS. Critical areas are identified. Methods and tools are described, which were developed to analyze and evaluate possible solutions to problems arising from dealing with these critical areas. Finally, a first-iteration concept is proposed. Since the concept envisions a system that could fit in SADARM-sized canisters, it could be first fabricated and tested within a simpler,

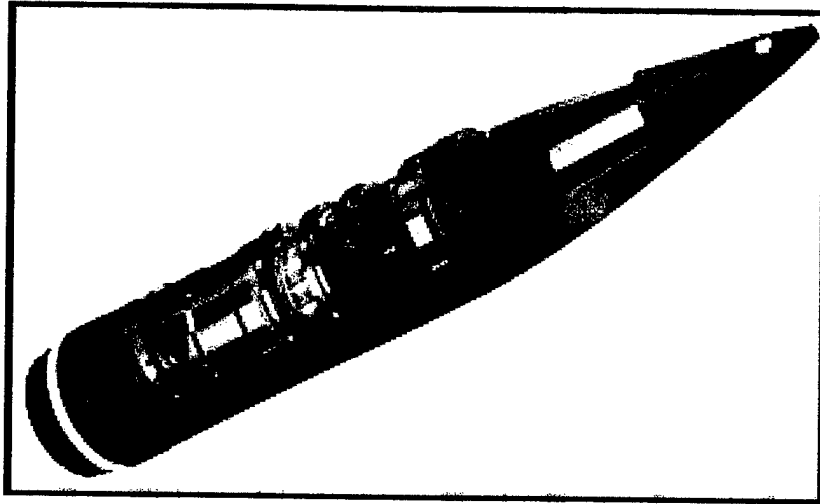


Figure 2. M898 Munition - Cutaway View.

cheaper munition platform. This would provide proof-of-concept demonstration for the artillery-delivered LWIMS.

3. Sensor Orientation

To send their received signal to the long-range radio, the sensor must have landed with the proper side facing up. By chance, this will occur 50% of the time. Modifications can be assessed based on the cost, the change in volume, and in the change in the probability of proper orientation.

For the base case, assume N sensors each cost C_o . There will be an average of $N/2$ sensors with the proper orientation at a cost of $2C_o$ each. Assume r is the change in volume due the modification; now instead of N sensors, there are N/r sensors available. Unless the sensor has been redesigned, r will be larger than 1; so the modification typically leads to a reduced number of sensors packaged in the round. To offset this decrease, an increase in the probability of proper orientation is needed. If p is used to represent the probability of proper orientation under the modification, then $p(N/r)$ sensors have the proper orientation. By equating this with the base

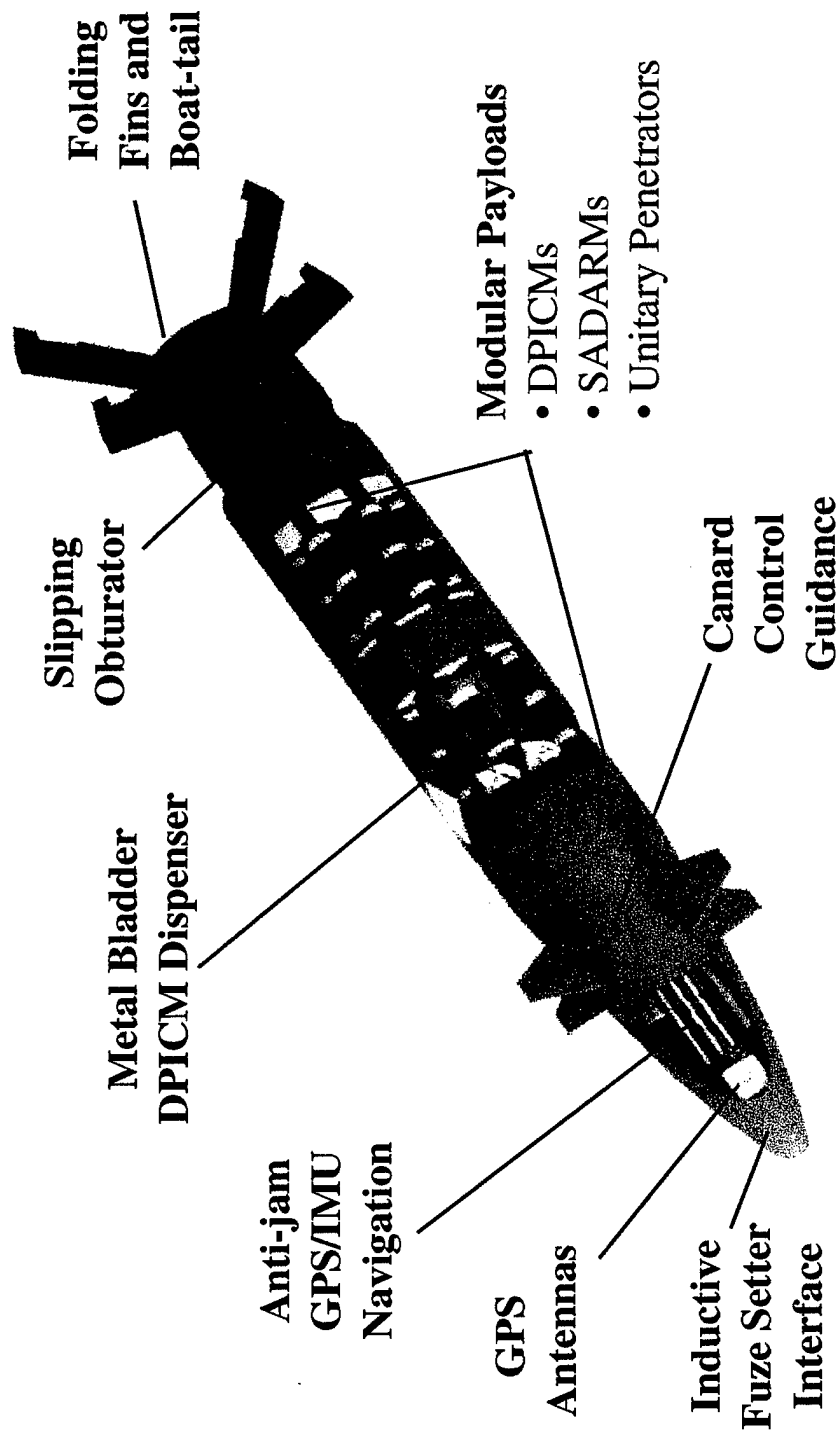


Figure 3. XM982 Munition - Cutaway View.

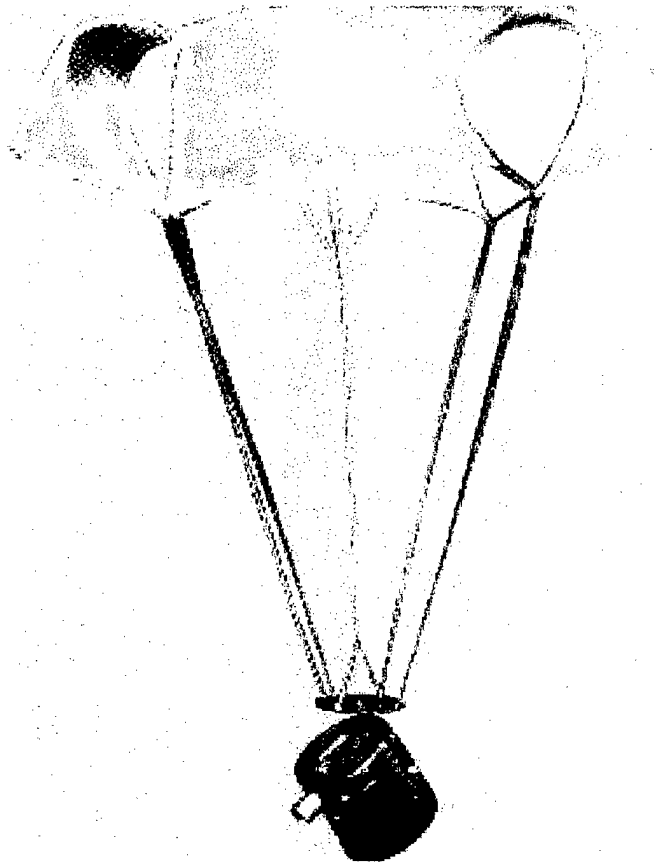


Figure 4. SADARM Canister Deployed With Parachute.

case of $N/2$, break-even value for p can be found to be $r/2$. Any volume change of more than 2 will decrease the expected number of properly oriented sensors. The increase in properly oriented sensors due to the modification is $p(N/r) - N/2$. As a design guideline, any modification that doubles the size of the sensing unit should not be considered.

Let the cost of the modified sensor be C . For the baseline situation, the cost for each properly oriented sensor is $2C_0$. In the modified situation, the total cost is $C(N/r)$ and there are $p(N/r)$ with the proper orientation. From a cost perspective, $C = 2pC_0$ is a break-even point.

Possible modifications would be a strip of material attached to the sensor's housing, ensuring that the sensors fell with the proper orientation. This would increase the overall drag on the sensor. Also, the possibility of shaping and weighting the sensor to increase the probability of proper orientation is worthy of investigation. A small version of the sand-filled-bottomed toys

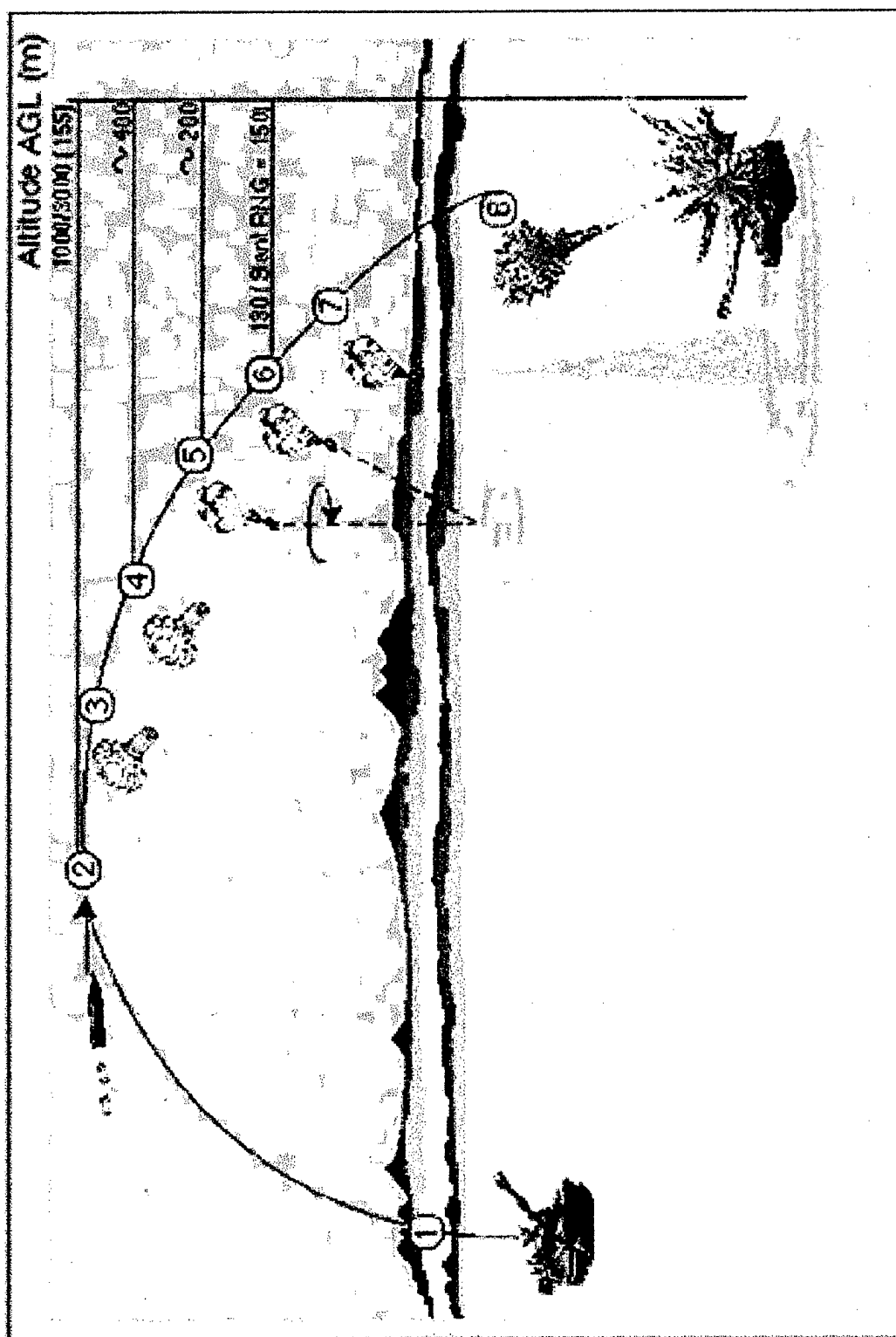


Figure 5. SADARM Canister Deployment Scenario.

made for children to punch seems plausible. A simple antenna on both sides of the node would eliminate orientation problems.

For our prototype round, the baseline situation was selected. The sensors are small and inexpensive. Any modification could easily double the size and would also probably double the cost. It should be noted that the variance in the number of properly oriented sensors would be greatest for this case. For example, the 96% coverage interval for 46 sensors, each with a 50% chance of proper orientation, is between 16 and 30 sensors.

4. Coverage Area

The effective coverage area of the sensor field is an issue. When sensors of the same type fall close together, their FOVs will overlap and thus decrease overall system effectiveness. The radius of the sensor's FOV will be called the sensor radius, and the transmitter range will refer to the maximum distance the transmitter can be from a sensor and still receive its signal. If the sensors are too far from the local transmitter, they will not be able to relay their information to the operations center. These two conflicting issues allow the investigation of the needed dispersion for the sensors given transmitter location errors and transmitter range. In the past, there have been investigations of the percent of coverage when specific shapes are dropped on other shapes given dispersion errors. For example, see Garwood (1947). These studies have been used to assess target damage. There are not any closed-form solutions to these problems; tables are typically made through simulation. A simulation was developed to evaluate the desired dispersion for the sensors. Parameters include the number of sensors, the dispersion of the sensors, the transmitter location error, radius of sensor coverage, and the range of sensor transmission.

A pattern for 30 sensors, each with a range of 20 and dispersion of 30, is shown in Figure 6 for a transmitter with a range of 50 and a dispersion of 10. Each sensor had a 50% chance of being oriented properly.

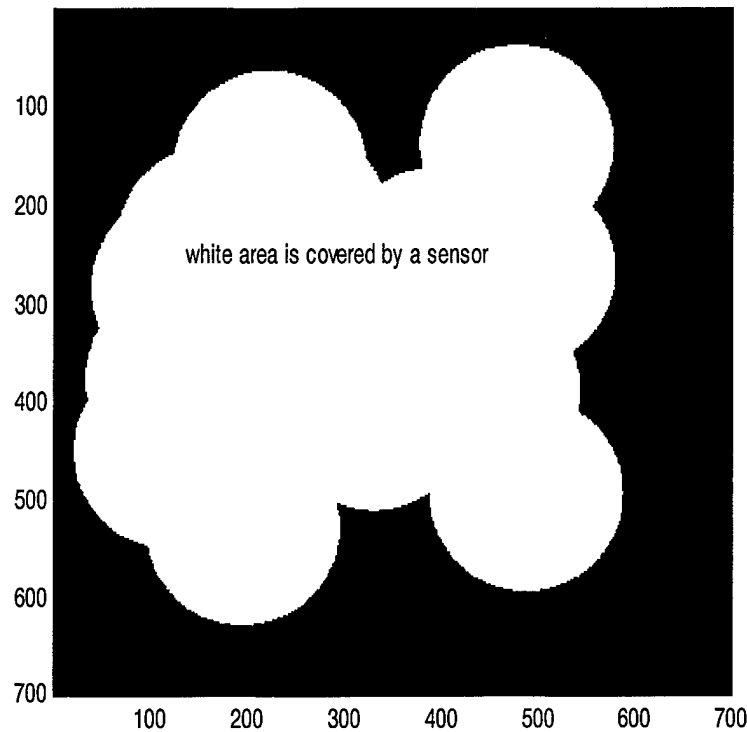


Figure 6. Coverage Pattern.

The number of sensors outside the transmitter range or the number of sensors within a given range band from the transmitter can be estimated using a circular Gaussian distribution. Design guidelines could be developed based on these estimates and the sensor radius.

Another simulation was developed to assess system effectiveness when each sensor has the ability to forward the signal to its neighbors. In this case, the transmitter needs to be within range of one sensor and then has access to all the information of sensors that connect directly or indirectly to each sensor in its immediate neighborhood. To maximize coverage area, multiple aimpoints are necessary. Sandmeyer (1986) discusses an algorithm to solve this to maximize artillery effectiveness. Thompson (1990) discusses this problem and its relationship to the theory of search. Koopman (1986) and Stone (1975) both discuss the theory of search. In this situation, the optimal pattern would be a grid of sensors separated by the diameter of the sensor FOV with the transmitter located near the center of the grid. The centrally located transmitter would be

within range of several sensors allowing more than one path for data transfer. Typical bomblet dispersion patterns are elongated in range and narrow in dispersion. The realization of the ideal pattern via artillery is not possible due to dispersion errors and the sensor orientation issue.

Although there was not enough time available to fully optimize the coverage pattern, a near optimal coverage was achieved for the following situations. It was assumed 49 sensors were available; each had a 50% chance of proper orientation. Grid and circular patterns of aimpoints were investigated. Parameters were adjusted until the change in coverage seemed to be buried in the noise level. Noise levels were high. To minimize sensor FOV overlap, the radio transmission distance for forwarding messages should be twice the sensor FOV. This observation can be supported by theoretical arguments; however, it is easy to understand that if sensors are forced to overlap their FOVs in order to communicate, the overlapping portion has wasted a portion of the potential sensor resource. It should be an LWIM design objective to make the radio relay range at least twice the sensor FOV radius.

The concept of an ideal coverage pattern allows the evaluation of suboptimal patterns via direct comparison. If each sensor has the proper orientation, then an ideal pattern is one where the FOVs of the sensors touch but do not overlap. The ideal case when sensor orientation is probabilistic is not so simple. This is further complicated when the sensors can only be placed at approximately the desired location. Using the simulations, it is possible to find a near optimal solution for a given situation and then use the "optimal" parameters as design criteria.

5. Terminal Velocity

The terminal velocity can be used to estimate the distance at which a projectile's motion aligns itself with gravity. Terminal velocity can be estimated from the drag and mass of a projectile. First, it is helpful to consider the one-dimensional case. If a force F is acting on a body and the resistance to the force is proportional to the velocity squared, we have a straightforward differential equation.

$$m \frac{dv}{dt} = F - bV^2.$$

If $k^2 = \frac{mF}{b}$, then the equation can be written as

$$\frac{dv}{dt} = \frac{-b}{m}(v^2 - k^2).$$

Solving this equation yields

$$v(t) = k \frac{1 + ce^{-pt}}{1 - ce^{-pt}}.$$

If $p = \frac{2kb}{m}$ and $c = \frac{v_0 - k}{v_0 + k}$, where v_0 is the initial velocity, the velocity will asymptotically approach k . This equation can be used to find the terminal velocity of a dropped object by letting F be the force due to gravity. Solving this same equation for $F = 0$ yields the following result:

$$v(t) = \frac{1}{\frac{1}{v_0} + \frac{b}{m}t}.$$

This expression asymptotically approaches zero. The distance traveled is found by integration and is described by the following expression:

$$\frac{m}{b} \ln\left(\frac{1}{v_0} + \frac{b}{m}t\right) - \frac{m}{b} \ln\left(\frac{1}{v_0}\right).$$

The distance traveled is the natural logarithm of a linear function. Using this expression, an upper bound for the lateral distance traveled can be established. It is also possible to approximate the initial velocity needed to attain a specified distance.

The two-dimensional case is more complex because the velocity term is an interaction of both the height and range terms. This interaction, in a sense, steals velocity from the range dimension as gravity causes the vertical velocity to increase asymptotically to its terminal velocity. The equations are as follows:

$$\dot{x} = -\cos(\theta) \frac{b}{m} v^2$$

$$\dot{y} = g - \frac{b}{m} v^2 \sin(\theta)$$

$$v^2 = \dot{x}^2 + \dot{y}^2$$

$$\theta = \tan^{-1}(\dot{y} / \dot{x}).$$

To solve this system, the initial conditions must be stated. Assume the sensors are expelled in the range dimension so that $\dot{y} = \theta = 0$ and $\dot{x} = v_0$. Choosing the expulsion velocity allows these equations to be solved numerically. The previous equation was realized in SIMULINK and solved numerically therein. See Figure 7 for a block diagram of the model. For horizontally launched sensors, the lateral speed approaches zero as the terminal velocity is attained. The value b is based on the drag coefficient; a discussion of this can be found in Army Special Text 9-153 (U.S. Army Ordnance School and U.S. Army Ballistic Research Laboratory 1964) or Sabersky, Acosta, and Hauptmann (1989). When $b = .0109$ and $m = .028$ kg, these equations approximate LWIM ejection. For an ejection speed of 10 and 20 m/s, the horizontal distance traveled is 44 and 80 m, respectively.

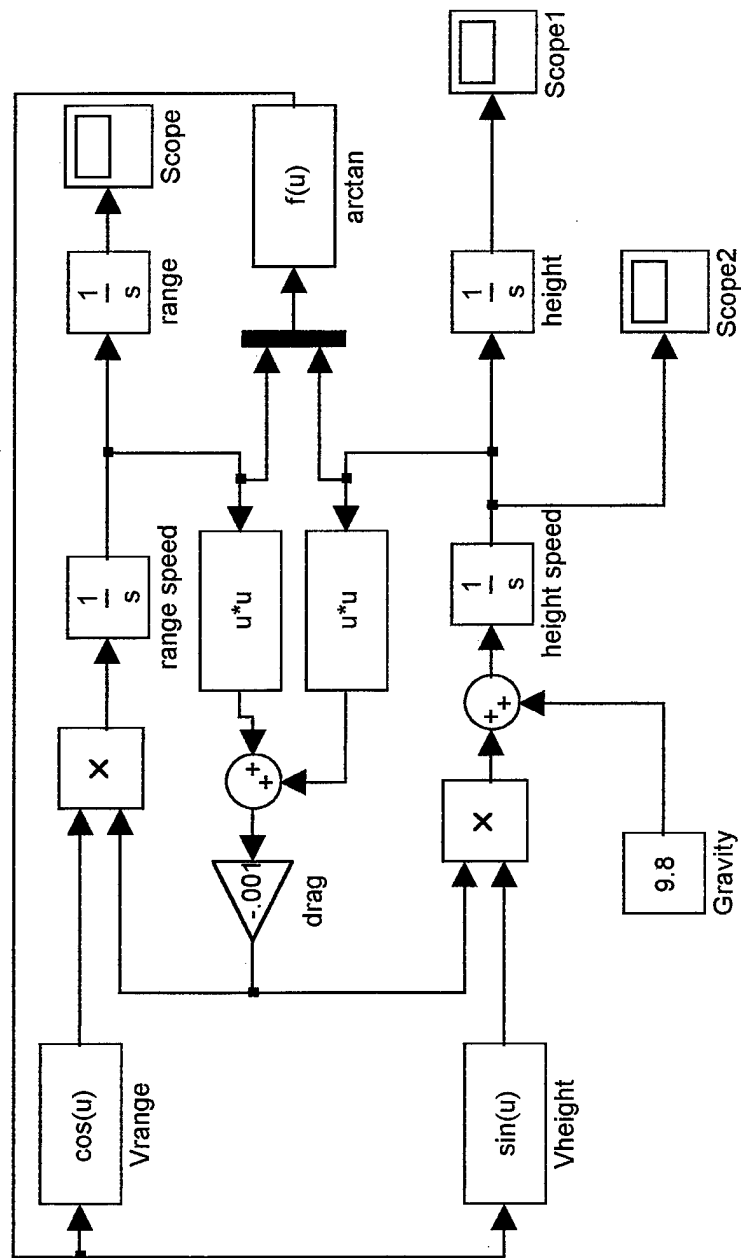


Figure 7. Bomblet Dispersion Model.

6. Concept Round

A container round with a canister similar to SADARM is considered the best candidate. The main concept is to disperse the sensors in a predetermined pattern in order to optimize the sensor coverage on the ground. The difference in the mass of the transmitter (i.e., long-range radio) and the sensors is an issue, as it affects the velocity and distance traveled. The problem caused by this can be minimized by keeping the sensors and transmitter together as long as possible. Dropping the transmitter in the middle of the sensor pattern increases the probability that the transmitter will be connected to the sensor network. Also being in the center minimizes the expected number of sensor relays, and the number of possible paths to the transmitter is maximized.

Encasing the sensors in a grenade similar to the M80 would more than double the size of the sensor. In the previous section on sensor orientation, it was shown that this would not be prudent. The low mass of the sensors presents a problem for ejection.

Sedney (1978) proposes a model for bomblet ejection from missiles. The major factors in the model are spin and force needed to penetrate the shear layer. If the canister is moving slowly, the shear layer will not be a problem for the sensors to traverse and can be ignored. A delivery system using a simple parafoil or a parachute designed to traverse the coverage area would solve problems associated with sensor ejection and allow improved coverage through artificial dispersion (i.e., timed, sequential, mechanized ejection). Actually, an unmanned aerial vehicle would be ideal for this task. Unfortunately, the time to arrive on station may be excessive. The XM982 and the M898 are high-accuracy artillery cargo rounds capable of delivering a canister near the area of interest.

As noted previously, a cargo round using M42 bomblets attains a circular coverage of approximately 75 m. In order to increase the coverage area, a parachute system, designed to circle or maneuver a canister above the desired coverage area, could be designed. If this was coupled with a sensor ejection mechanism capable of laterally shooting out (or vertically

dropping) the sensors, large coverage areas are achievable. For this case, the effect of the wind could help increase the coverage area; however, excessive winds could increase the sensor spacing to the point of not being able to communicate with each other.

Coverage patterns for circular and spiral sets of aimpoints were investigated. The parachute design problem is minimized for a circular pattern. A spiral pattern allows the transmitter to be dropped first in the middle of the patterns and may approach optimal coverage. Simulation runs for these patterns indicate expected coverage is near a maximum when there are 10 m in between the aimpoints forming a spiral pattern with 10 m between the consecutive spirals.

The development of a round requires several different phases. In the first phase, a concept is proposed to satisfy a requirement. In the intermediate phases, tests are performed on the components to demonstrate they are robust enough to function in an artillery system. Finally, a round is selected or designed as the system carrier and the system goes through an operational test.

7. Launch Issues and LWIMS Packaging

The forces acting on the sensors and the radio during launch must be considered by the design team. The components could be subjected to forces of 15,000 g.

One hypothetical packaging scheme is investigated in this report for the proof-of-concept round and is shown in Figures 8 and 9. A traditional circular or parafoil-type parachute could be utilized to allow the canister to deploy the LWIMS. Note, Figure 8 mainly shows size relationship between the canister volume and the sensors and long-range radio. A single-canister-packaging scheme such as this one could provide proof-of-concept verification at relatively low cost with a relatively simple helicopter drop test, initially, and/or a 155-mm gun-launch test. Note, in a proof-of-concept drop or gun test, it is envisioned that the long-range radio, subsequent to the sensors being deployed on the ground, could be "hand" inserted near the distribution of sensors; this insertion would be justified by assuming that the final design for an

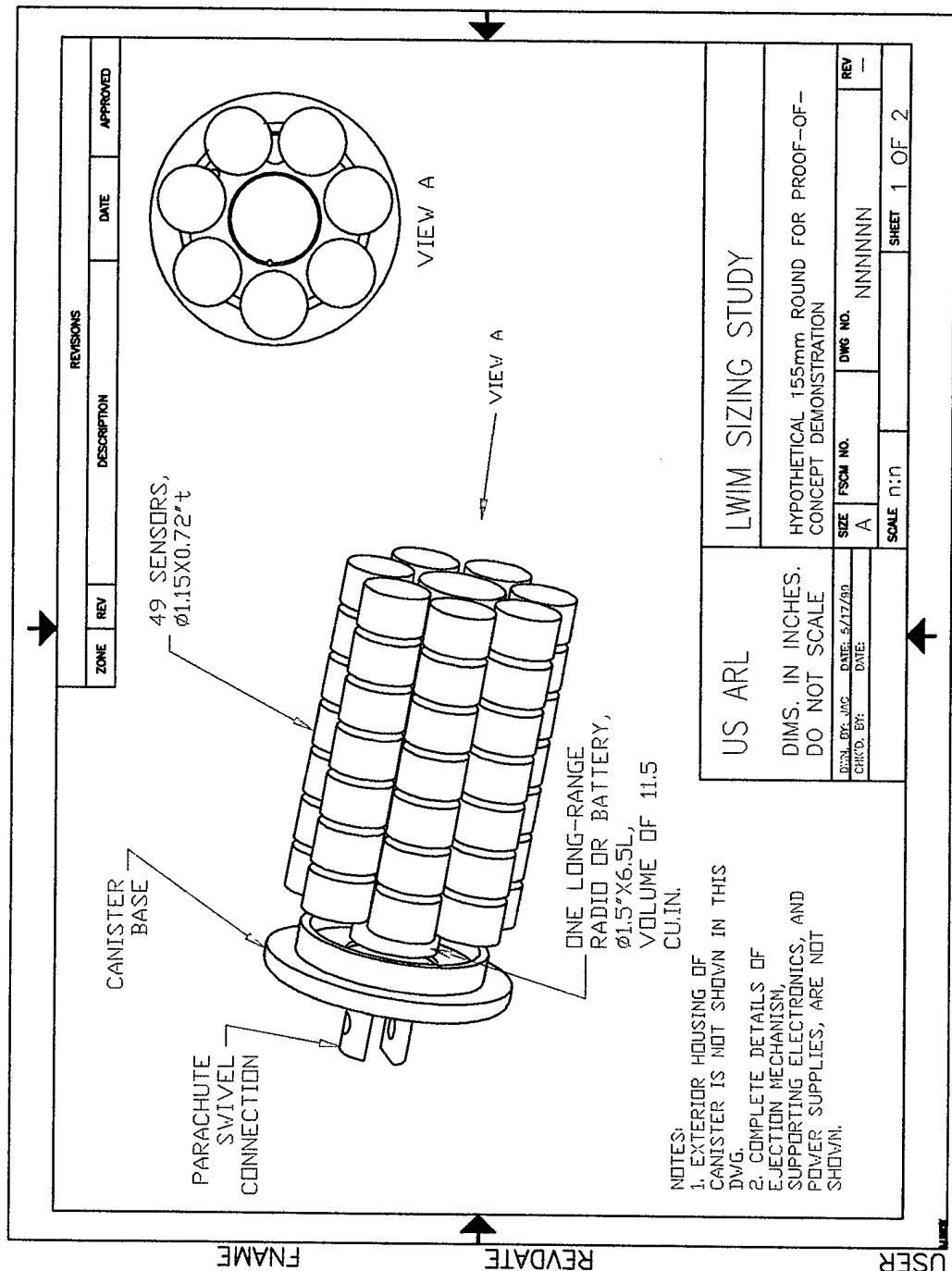


Figure 8. Hypothetical Packaging Scheme - Sheet 1.

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VERTICAL DROP EJECTION METHOD WITH SPRING AND GRAVITY-ASSISTED FEED OF SENSORS.

US ARL	LWIM EJECTION METHOD
DIMS. IN INCHES. DO NOT SCALE.	
HYPOTHETICAL 155mm ROUND FOR PROOF-OF-CONCEPT DEMONSTRATION	
DESIGNED BY: JAC DATE: 5/17/99	SIZE: A FSCM NO.: A DWG NO.: NNNNNN
CHECKED BY: DATE:	SCALE: 1:1 SHEET: 2 OF 2

Figure 9. Hypothetical Packaging Scheme - Sheet 2.

artillery-deployed munition platform would inherently provide for this via deployment of a second long-range radio-carrying canister. As noted earlier, the SADARM-sized two-canister design would be ideally suited for the LWIM final flight test unit. One canister would hold the relatively large long-range radio and a few sensors, while the second would hold the bulk of the sensors (see Figure 10). The additional sensors in the first canister increase the likelihood of the long-range radio being part of the network.

The vertically dropped ejection mechanism for this hypothetical round shown in Figure 9 would be typical of any munition considered to deploy the LWIM components. It is envisioned that a motor and gear-driven circular plate with a circular cutout could be sequentially rotated to allow a controlled deployment of a single, spring, and gravity-fed sensor from stacks of these sensors within the canister. Deployment control would be determined utilizing feedback from timing circuits, standoff-distance-to-ground transducers, altitude sensors, etc. Further, an integral electromechanical or strictly mechanical switch [or switches] could be designed to brake the adjacent sensor from dropping out with the first sensor within each stack. A second ejection mechanism can be envisioned, whereby, providing for the sensors to be ejected laterally or radially with respect to the canister (Condon, Hollis, and Brandon 1997). This second mechanism design could allow for a higher probability of sensor coverage at the expense of increased mechanism volume and lower sensor count per canister. These tradeoffs and choice of mechanism design would need further consideration.

Functioning of the mechanical and electrical subsystems within each canister could be verified by either drop or gun-launch test, but the integrity of the packaging methods and the individual mechanical and electrical components, under typical 155-mm gun-launch accelerations and spin rates, could be first shock-table tested, air gun tested, and flight simulator tested (i.e., ground tested) and then finally validated by the gun-launch testing (Davis et al. 1997). Following successful proof-of-concept testing, dedicated rounds could then be retrofitted with new canisters providing an optimized LWIMS configuration. The supporting electronics, power supply, and ejection mechanisms and structures would be specified, analyzed and designed, and gun-hardened based on past experience in the smart munitions, artillery-based field (D'Amico 1998; Burke et al. 1997; or Ferguson et al. 1998).

This proof-of-concept packaging and sizing study effort is meant to accommodate the simulation effort described earlier in this report and the hypothetical concept round would also provide a baseline testing platform for the LWIMS should support continue on this effort.

The SADARM-type canisters deployed from an M898 or XM892 munition could be best suited for the LWIMS and provide the best sensor coverage on the ground. What is unique and critical in the SADARM-type delivery system is the parachute design. The first LWIM canister, holding the long-range radio and a small number of sensors, would be ejected from the munition main body and deploy traditional circular drogue and main parachutes. The second canister, holding the bulk of the sensors, would deploy a parafoil-type main parachute, providing for a diverging spiral decent and optimized sensor dispersal. This scheme could allow the first canister to drop to the ground within close proximity to the second canister's deployed sensor grouping. Further, the long-range radio and small number of associated sensors would be ejected from the first canister at a predetermined time or altitude to provide the best coverage area and ensure integrity of the network.

8. Design Excursions

Placing a patch antenna on the battery side of a node would ensure proper orientation of the sensor. This modification would not change the volume of the sensor and would double the expected number of operating sensors. The increase in the number and reliability of the sensors allows the distance between aimpoints to be increased.

If the transmission distance is the sensor FOV, then, in order to communicate, the overlap of the sensor FOV is extreme. Consider three sensors in a line. The middle sensor must be centered on the perimeter of both its neighbors. In this situation, 78% of the central sensor's FOV overlaps its neighbors. In this case, the wasted resource is extreme. When the sensor relay distance is less than twice the FOV, double coverage by sensing elements is forced. Radio ranges of 1.5 and 2 times the sensor FOV were investigated. Table 1 shows some of the cases

Table 1. LWIM Coverage for Spiral Aimpoint Pattern

Spacing	Transmitter Range	Sensor FOV	SD (Sensor)	P (Orientation)	Average Coverage	SD Coverage
10	20	20	20	.5	11,500	2,540
15	20	20	20	1	21,660	2,151
17	20	20	20	1	17,992	4,716
20	30	20	20	1	34,936	4,028
19	30	20	20	1	35,050	2,409
18	30	20	20	1	32,988	3,541
25	40	20	20	1	49,586	2,335
27	40	20	20	1	52,580	3,307
29	40	20	10	1	61,823	1,838
32	40	20	10	1	62,819	6,059
32	40	20	5	1	76,914	985
34	40	20	5	1	81,598	1,728

investigated. Although the numbers in the table can be thought of in terms of any units, meters and meters squared provide the most convenient interpretation.

Each value of average coverage is based on 15 replications of the indicated conditions. A spiral pattern of aimpoints with the indicated spacing along the spiral and between the spirals was chosen. Increasing the transmitter range, adding a patch antenna, and decreasing the delivery area of the sensors all increase the expected coverage area. The delivery error of the sensor nodes effectively blurs the desired pattern. A response surface could be fit to this data; however refinement of the findings is not currently necessary. If desired, a future study could be done basing all units on the sensor FOV. A model could be developed to fit the generalized situation, and then the result could be scaled to fit the particular problem.

9. Conclusion

This report introduced a concept round for the delivery and emplacement of the LWIMS. Issues associated with sensor orientation and system coverage were used to develop criteria for a

packaging system. Using these criteria, it was possible to formulate an artillery-delivered system. The system was selected so it would be straightforward to move to an operational test. Improvements in system coverage can be investigated by using the simulation toolbox to implement ideas from the theory of search. These improvements in coverage would be implemented through new mechanical designs.

Several design guidelines were mentioned in this report:

- (1) If a design requires the sensor unit to more than double in size, the expected coverage area will decrease
- (2) If a design more than doubles the cost of a sensing unit, then the expected cost per operating sensor must increase.
- (3) The sensor relay range should be twice its FOV.
- (4) An antenna applied to both sides of the node will result in a coverage increase.
- (5) Using the simulation toolbox, design criteria can be generated to maximize expected coverage.

The expected coverage is maximized for the situation considered in this report. The ideas used can be reapplied to similar problems to maximize the effective use of resources.

The XM982 round will enable the system to be delivered accurately to ranges of up to 50 km. Using this round as the carrier and a canister system to optimize the emplacement of individual nodes will provide maximum coverage for an artillery-deployed LWIMS.

10. References

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